MATRIX FORMULATION OF ELECTRIC SUPPLY SYSTEM OF INDUSTRIAL ENTERPRISE

Sevinch Fazliddinova

3rd year student of the faculty of Energy

Bukhara State Technical Institute

Abstract: The article presents the electric supply system expressed in the form of matrix equations. Equations that are convenient for optimizing the parameters of the electric supply scheme have been derived. The "MATLAB" environment was used for calculating the matrix equations. An algorithm for calculating losses in cable routes at all stages of the enterprise's electric supply system is provided.

Keywords: mathematical modeling, electric supply system, matrix equation, optimization, cable route, minimizing losses, modeling electric supply systems, automated calculations, parameters of electric supply schemes, power losses.

The matrix model of the electric supply system (ESS) of an industrial enterprise refers to a matrix that systematically arranges elements describing the electric supply scheme and its components in a specific order [1]. Expressing through matrix equations is most convenient for a scheme that has a hierarchical structure, such as a radial scheme with a single transformer substation. However, in practice, there are also schemes that differ from this type. Therefore, such schemes can be brought into a matrix representation of the ESS through certain rules and simplifications. This matrix can also be referred to as the state matrix of the ESS, as it consists of passport data describing the electric supply scheme (ESS) and its elements in that specific state. The technical and economic indicators of the ESS are determined through these matrices. We will examine this issue based on the scheme shown in Figure 1.

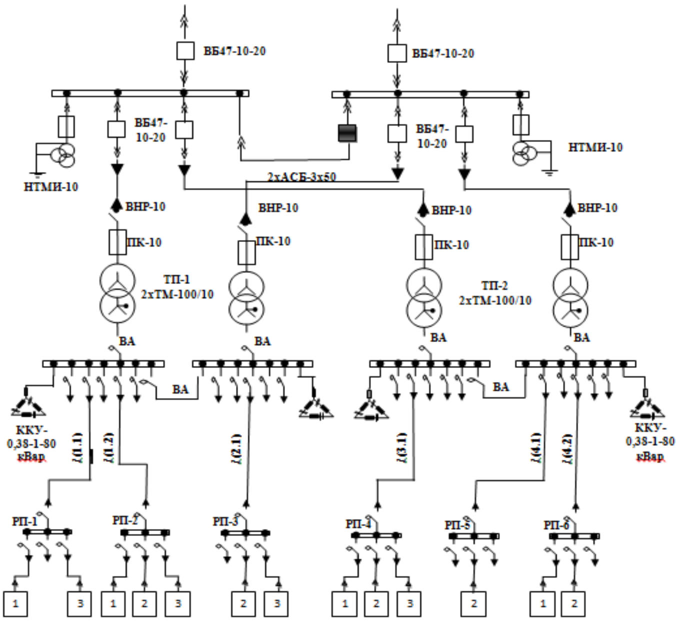

Figure 1. Electric supply scheme of an industrial enterprise.

The size of the state matrix of the electric supply system (ESS) is determined by the number of distribution points and the number of connected consumers. For example, if there are a maximum of 3 distribution points at the substation and a maximum of 4 connected consumers at a distribution point, the number of rows in the matrix will be 3, the number of columns will be 4, and the total number of elements in the matrix will be 12. A value of zero is assigned to matrix elements that do not correspond to consumers.

Matrix equations are constructed based on substations. The columns of the matrix represent the numbers of the distribution cabinets, while the rows indicate the consumers connected to those cabinets. As can be seen from the scheme, the consumers at the distribution points are not evenly distributed, and there are two transformers at the substations. We will check the ESS against the following conditions:

The transformers have the same load and type and operate in parallel mode.

The types and loads of the cable routes supplying the transformers are the same and operate in parallel line style.

If the ESS meets the above requirements, matrices can be constructed for the substations. Otherwise, matrices will be constructed based on the transformers.

Based on these simplifications, we will generate the following state matrices for the scheme shown in Figure 1. The calculations will be performed in the "MATLAB" environment.

Equation of the powers of consumers connected to the first workshop substation:

$$\mathrm{S}_{1(i,j)} = \begin{vmatrix} S_{1(1,1)} & S_{1(1,2)} & S_{1(1,3)} \\ S_{1(2,1)} & S_{1(2,2)} & S_{1(2,3)} \\ S_{1(3,1)} & S_{1(3,2)} & S_{1(3,3)} \end{vmatrix} = \begin{vmatrix} 20+5i & 0 & 18+11i \\ 15+5i & 18+5i & 27+20i \\ 0 & 15+10i & 10+1.5i \end{vmatrix} \qquad (1)$$

Equation of the powers of consumers connected to the second workshop substation:

$$\mathrm{S}_{2(i,j)} = \begin{vmatrix} S_{2(1,1)} & S_{2(1,2)} & S_{2(1,3)} \\ S_{2(2,1)} & S_{2(2,2)} & S_{2(2,3)} \\ S_{2(3,1)} & S_{2(3,2)} & S_{2(3,3)} \end{vmatrix} = \begin{vmatrix} 24+15i & 20+7i & 20+7.5i \\ 0 & 10+4i & 0 \\ 25+6.5i & 26+15i & 0 \end{vmatrix} \qquad (2)$$

Matrix equation of the cable route resistances:

$$\mathrm{R}_{0,1(i,j)} = \begin{vmatrix} R_{0,1(1,1)} & R_{0,1(1,2)} & R_{0,1(1,3)} \\ R_{0,1(2,1)} & R_{0,1(2,2)} & R_{0,1(2,3)} \\ R_{0,1(3,1)} & R_{0,1(3,2)} & R_{0,1(3,3)} \end{vmatrix} = \begin{vmatrix} 0.64 & 0 & 0.48 \\ 0.4 & 0.64 & 0.35 \\ 0 & 0.5 & 0.64 \end{vmatrix} \qquad (3)$$

$$\mathrm{R}_{0,2(i,j)} = \begin{vmatrix} R_{0,2(1,1)} & R_{0,2(1,2)} & R_{0,2(1,3)} \\ R_{0,2(2,1)} & R_{0,2(2,2)} & R_{0,2(2,3)} \\ R_{0,2(3,1)} & R_{0,2(3,2)} & R_{0,2(3,3)} \end{vmatrix} = \begin{vmatrix} 0.7 & 0.4 & 0.5 \\ 0 & 0.6 & 0 \\ 0.8 & 0.75 & 0 \end{vmatrix} \qquad (4)$$

Length of the cable routes:

$$\mathrm{L}_{1(i,j)} = \begin{vmatrix} L_{1(1,1)} & L_{1(1,2)} & L_{1(1,3)} \\ L_{1(2,1)} & L_{1(2,2)} & L_{1(2,3)} \\ L_{1(3,1)} & L_{1(3,2)} & L_{1(3,3)} \end{vmatrix} = \begin{vmatrix} 0.08 & 0 & 0.04 \\ 0.11 & 0.022 & 0.05 \\ 0 & 0.02 & 0.03 \end{vmatrix} \qquad (5)$$

$$\mathrm{L}_{2(i,j)} = \begin{vmatrix} L_{2(1,1)} & L_{2(1,2)} & L_{2(1,3)} \\ L_{2(2,1)} & L_{2(2,2)} & L_{2(2,3)} \\ L_{2(3,1)} & L_{2(3,2)} & L_{2(3,3)} \end{vmatrix} = \begin{vmatrix} 0.018 & 0.09 & 0.06 \\ 0 & 0.056 & 0 \\ 0.042 & 0.1 & 0 \end{vmatrix} \qquad (6)$$

The voltage for all consumers and cable routes is 0.4 kV, and the currents in the cable routes are determined by the following expression:

$$\mathrm{I}_{(i,j)} = \frac{\mathrm{S}_{(i,j)}}{\sqrt{3}\cdot 0.4}; \qquad (7)$$

$$\mathrm{I}_{1(i,j)} = \begin{vmatrix} I_{1(1,1)} & I_{1(1,2)} & I_{1(1,3)} \\ I_{1(2,1)} & I_{1(2,2)} & I_{1(2,3)} \\ I_{1(3,1)} & I_{1(3,2)} & I_{1(3,3)} \end{vmatrix} = \begin{vmatrix} 29.79 & 0 & 30.48 \\ 22.85 & 26.99 & 48.55 \\ 0 & 26.05 & 14.61 \end{vmatrix} \qquad (8)$$

$$\mathrm{I}_{2(i,j)} = \begin{vmatrix} I_{2(1,1)} & I_{2(1,2)} & I_{2(1,3)} \\ I_{2(2,1)} & I_{2(2,2)} & I_{2(2,3)} \\ I_{2(3,1)} & I_{2(3,2)} & I_{2(3,3)} \end{vmatrix} = \begin{vmatrix} 40{,}89 & 30{,}62 & 30{,}86 \\ 0 & 15{,}56 & 0 \\ 37{,}33 & 43{,}38 & 0 \end{vmatrix} \qquad (9)$$

We determine the losses in the cable routes using the following expression:

$$\Delta\mathrm{P}_{(i,j)} = 3\cdot I_{(i,j)}^{2}\cdot \mathrm{R}_{0(i,j)}\cdot L_{(i,j)}; \qquad (10)$$

The result of the multiplication appears in the following matrix:

$$\Delta\mathrm{P}_{1(i,j)} = \begin{vmatrix} \Delta\mathrm{P}_{1(1,1)} & \Delta\mathrm{P}_{1(1,2)} & \Delta\mathrm{P}_{1(1,3)} \\ \Delta\mathrm{P}_{1(2,1)} & \Delta\mathrm{P}_{1(2,2)} & \Delta\mathrm{P}_{1(2,3)} \\ \Delta\mathrm{P}_{1(3,1)} & \Delta\mathrm{P}_{1(3,2)} & \Delta\mathrm{P}_{1(3,3)} \end{vmatrix} = \begin{vmatrix} 0.14 & 0 & 0.054 \\ 0.069 & 0.031 & 0.124 \\ 0 & 0.02 & 0.012 \end{vmatrix} \qquad (11)$$

$$\Delta\mathrm{P}_{2(i,j)} = \begin{vmatrix} \Delta\mathrm{P}_{2(1,1)} & \Delta\mathrm{P}_{2(1,2)} & \Delta\mathrm{P}_{2(1,3)} \\ \Delta\mathrm{P}_{2(2,1)} & \Delta\mathrm{P}_{2(2,2)} & \Delta\mathrm{P}_{2(2,3)} \\ \Delta\mathrm{P}_{2(3,1)} & \Delta\mathrm{P}_{2(3,2)} & \Delta\mathrm{P}_{2(3,3)} \end{vmatrix} = \begin{vmatrix} 0.063 & 0.101 & 0.086 \\ 0 & 0.024 & 0 \\ 0.14 & 0.423 & 0 \end{vmatrix} \qquad (12)$$

By adding the currents of the consumers in the distribution cabinet, we determine the currents of the cables coming from the workshop substation to the distribution cabinet. The currents in the cable routes of the second stage of the electrical supply will be as follows:

$$J_{(k,n)} = \begin{vmatrix} J_{1,1} & J_{1,2} & J_{1,3} \\ J_{2,1} & J_{2,2} & J_{2,3} \end{vmatrix} = \begin{vmatrix} 60.27 & 98.4 & 40.66 \\ 102.39 & 15.56 & 80.71 \end{vmatrix} \qquad (13)$$

The columns of the matrix represent the number of the workshop substation, while the rows indicate the numbers of the distribution cabinets. The resistances of these cable routes are expressed in the following matrix form:

$$R_{0,2(k,n)} = \begin{vmatrix} R_{0,2(1,1)} & R_{0,2(1,2)} & R_{0,2(1,3)} \\ R_{0,2(2,1)} & R_{0,2(2,2)} & R_{0,2(2,3)} \end{vmatrix} = \begin{vmatrix} 0.52 & 0.42 & 0.62 \\ 0.43 & 0.94 & 0.65 \end{vmatrix} \quad (14)$$

Matrix equation of the cable route lengths:

$$L_{(k,n)} = \begin{vmatrix} L_{1,1} & L_{1,2} & L_{1,3} \\ L_{2,1} & L_{2,2} & L_{2,3} \end{vmatrix} = \begin{vmatrix} 0.08 & 0.056 & 0.071 \\ 0.082 & 0.063 & 0.074 \end{vmatrix} \quad (15)$$

The losses in the cable routes will be at the following values:

$$\Delta P_{(k,n)} = \begin{vmatrix} \Delta P_{1,1} & \Delta P_{1,2} & \Delta P_{1,3} \\ \Delta P_{2,1} & \Delta P_{2,2} & \Delta P_{2,3} \end{vmatrix} = \begin{vmatrix} 0.453 & 0.683 & 0.218 \\ 1.108 & 0.043 & 0.939 \end{vmatrix} \quad (16)$$

Thus, the losses in the low-voltage cable routes of the industrial enterprise have been determined. The disadvantage of expressing the electrical supply scheme (ESS) using two-dimensional matrices is that the enterprise's electrical transmission technology (ETT) cannot be represented with a single matrix. This limitation can be overcome by using three-dimensional matrices. This allows for the expression and calculation of multiple substation ESSs through a single state matrix in the "MATLAB" environment.

The above example will be expressed using a three-dimensional matrix. The placement of the elements of the three-dimensional matrix can generally be chosen freely. For instance, if the distribution points are written in the columns of the matrix and the consumers in the rows, or vice versa, it will not affect the results of the calculations. However, since it is more convenient to add the matrix columns and the currents of the higher-level cable routes are determined by the sum of the lower-level cable route currents, we will place the consumers in the columns. Thus, for the ESS shown in Figure 1, we obtain the following three-dimensional state matrix:

$$\left\| S_{ijk} \right| \; (i, j, k = 1,2,3) \quad (17)$$

State matrix of the power of the consumers from two substations:

$$S_{ijk} = \left\| \begin{matrix} S_{111} & S_{121} & S_{131} \\ S_{211} & S_{221} & S_{231} \\ S_{311} & S_{321} & S_{331} \end{matrix} \right| \begin{matrix} S_{112} & S_{122} & S_{132} \\ S_{212} & S_{222} & S_{232} \\ S_{312} & S_{322} & S_{332} \end{matrix} \right\|^{(k)} \underset{(i)}{\downarrow}^{\rightarrow (j)} =$$

$$= \left\| \begin{matrix} 20+5i & 15+5i & 0 \\ 0 & 18+5i & 35+20i \\ 18+11i & 27+20i & 25+7.5i \end{matrix} \right| \begin{matrix} 24+15i & 0 & 25+6.5i \\ 20+7i & 10+4i & 26+15i \\ 20+7.5i & 0 & 0 \end{matrix} \right\| \quad (18)$$

State matrix of the comparative resistances of the cable routes in the electrical supply scheme:

$$R_{ijk} = \left\| \begin{matrix} R_{111} & R_{121} & R_{131} \\ R_{211} & R_{221} & R_{231} \\ R_{311} & R_{321} & R_{331} \end{matrix} \right| \begin{matrix} R_{112} & R_{122} & R_{132} \\ R_{212} & R_{222} & R_{232} \\ R_{312} & R_{322} & R_{332} \end{matrix} \right\| = \left\| \begin{matrix} 0.64 & 0.4 & 0 \\ 0 & 0.64 & 0.5 \\ 0.48 & 0.35 & 0.64 \end{matrix} \right| \begin{matrix} 0.7 & 0 & 0.8 \\ 0.4 & 0.6 & 0.75 \\ 0.5 & 0 & 0 \end{matrix} \right\| \quad (19)$$

State matrix of the cable route lengths in the electrical supply scheme:

$$L_{ijk}=\left\|\begin{array}{ccc|ccc} L_{111} & L_{121} & L_{131} & L_{112} & L_{122} & L_{132} \\ L_{211} & L_{221} & L_{231} & L_{212} & L_{222} & L_{232} \\ L_{311} & L_{321} & L_{331} & L_{312} & L_{322} & L_{332} \end{array}\right\|=\left\|\begin{array}{ccc|ccc} 0.08 & 0.11 & 0 & 0.018 & 0 & 0.042 \\ 0 & 0.022 & 0.02 & 0.09 & 0.056 & 0.1 \\ 0.04 & 0.05 & 0.03 & 0.06 & 0 & 0 \end{array}\right\| \quad (20)$$

The power matrix of the currents in the cable routes is determined by dividing by the voltage of 0.4 kV:

$$\mathrm{I}_{i,j,k}=\frac{\mathrm{S}_{i,j,k}}{\sqrt{3}\cdot 0.4}; \qquad (21)$$

$$I_{ijk}=\left\|\begin{array}{ccc|ccc} I_{111} & I_{121} & I_{131} & I_{112} & I_{122} & I_{132} \\ I_{211} & I_{221} & I_{231} & I_{212} & I_{222} & I_{232} \\ I_{311} & I_{321} & I_{331} & I_{312} & I_{322} & I_{332} \end{array}\right\|=\left\|\begin{array}{ccc|ccc} 29.79 & 22.85 & 0 & 40.9 & 0 & 37.33 \\ 0 & 26.99 & 58.25 & 30.62 & 15.56 & 43.38 \\ 30.48 & 48.55 & 37.72 & 30.87 & 0 & 0 \end{array}\right\| \quad (22)$$

The power losses in the cable routes supplying the consumers are determined by the product of the following matrices:

$$\Delta\mathrm{P}_{i,j,k}=3\cdot I_{i,j,k}^{2}\cdot \mathrm{R}_{i,j,k}\cdot L_{i,j,k}; \qquad (23)$$

The result of the multiplication appears in the following matrix:

$$\Delta P_{ijk}=\left\|\begin{array}{ccc|ccc} \Delta P_{111} & \Delta P_{121} & \Delta P_{131} & \Delta P_{112} & \Delta P_{122} & \Delta P_{132} \\ \Delta P_{211} & \Delta P_{221} & \Delta P_{231} & \Delta P_{212} & \Delta P_{222} & \Delta P_{232} \\ \Delta P_{311} & \Delta P_{321} & \Delta P_{331} & \Delta P_{312} & \Delta P_{322} & \Delta P_{332} \end{array}\right\|=$$

$$=\left\|\begin{array}{ccc|ccc} 0.136 & 0.069 & 0 & 0.063 & 0 & 0.14 \\ 0 & 0.031 & 0.102 & 0.101 & 0.024 & 0.423 \\ 0.053 & 0.124 & 0.082 & 0.085 & 0 & 0 \end{array}\right\| \qquad (24)$$

Thus, to calculate the losses in the cable routes of the electrical supply scheme, 6 three-dimensional matrices were used instead of 12 two-dimensional matrices. Utilizing a matrix model for energy balances facilitates the complete construction of the energy balance in a single calculation process, improves the accuracy of calculations, and simplifies the execution of multiple scenarios and corrective calculations.

REFERENCES:

1. Sadullaev N.N., Shoboev A.Kh. The use of matrix equations in optimizing the power supply system of enterprises. // Development of Science and Technology. Scientific and Technical Journal. – Bukhara, 2015. No. 3. — pp. 4–8.
2. Sokolov N.P. Introduction to the Theory of Multidimensional Matrices. Kyiv. Publishing House "Naukova Dumka," 1971. — 176 pp.